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Abstract

The application of stereo technology to new, integrated pictorial display formats has been effective in situational awareness enhancements, and stereo has been postulated to be effective for the declutter of complex informational displays. This paper reports a full-factorial workstation experiment performed to verify the potential benefits of stereo cueing for the declutter function in a simulated tracking task. The experimental symbology was designed similar to that of a conventional flight director, although the format was an intentionally confused presentation that resulted in a very cluttered dynamic display. The subject's task was to use a hand controller to keep a tracking symbol, an "X," on top of a target symbol, another X, which was being randomly driven. In the basic tracking task, both the target symbol and the tracking symbol were presented as red X's. The presence of color coding was used to provide some declutter, thus making the task more reasonable to perform. For this condition, the target symbol was coded red, and the tracking symbol was coded blue. Noise conditions, or additional clutter, were provided by the inclusion of randomly moving, differently colored X symbols. Stereo depth, which was hypothesized to declutter the display, was utilized by placing any noise in a plane in front of the display monitor, the tracking symbol at screen depth, and the target symbol behind the screen. The results from analyzing the performances of eight subjects revealed that the stereo presentation effectively offsets the cluttering effects of both the noise and the absence of color coding. The potential of stereo cueing to declutter complex informational displays has therefore been verified; this ability to declutter is an additional benefit from the application of stereoptic cueing to pictorial flight displays.

Introduction

With the rapid advances in modern graphics display generators, it is now possible to produce high-fidelity, real-time images of real-world scenes ("real-world" pictorial displays). With current electronic display technology, it is also possible to incorporate true depth cueing (via stereopsis techniques) into the scene elements of the display. Advanced pictorial flight display concepts that embody three-dimensional (3-D) images are being conceived and evaluated at various flight display research laboratories, including Langley Research Center. Innovative concepts are sought that exploit the power of modern graphics display generators and stereopsis cueing, not only in situational awareness enhancements of pictorial displays but also in displays that declutter complex informational presentations.

The use of stereoptic presentations of information that has three dimensions, rather than the more conventional two-dimensional presentation of such information, potentially offers numerous advantages. These possible advantages have been investigated for years within the flight display community (refs. 1 to 24). Most of these investigations have focused on flight task performance (refs. 1 to 16). These studies have reported favorable subjective opinions concerning the value of stereopsis cueing, and when objective data were obtained, the data generally demonstrated modest task performance gains, or at least no degradations, compared with performance using nonstereo displays. These performance gains and the favorable subjective evaluations are generally attributed to the increased situational awareness provided by stereopsis cueing.

References 8 and 16 examine the use of stereopsis cueing as an alerting function in monitoring task displays. Both studies show stereopsis to be ineffective as an alerting cue, although one might infer that depth cueing is ineffective only because it is used away from the subject's fixation point, where stereoacuity is considerably reduced.

Stereopsis cueing intuitively seems to be an effective means to declutter complex informational displays. One could easily envision enhancing a cluttered head-down or head-up primary flight display with depth cueing. For example, separating the heading information from the pitch information in such a display might prove beneficial. The goal of this research was to verify the potential of stereo cueing to declutter information in a simulated tracking task. The piloting task for the study was designed to be similar to tracking a conventional flight director, although the format presentation was intentionally chaotic so that it resulted in a very cluttered dynamic display. It was hypothesized that the application of stereoptic cueing would effectively declutter such a format and that this effectiveness could be measured as an improvement in tracking performance.

Experimental Tasks and Participating Subjects

A two-axis pursuit tracking task was chosen as the primary task for the experiment. The experimental symbology was designed to be similar to that of a conventional flight director (which presents a compensatory tracking task), although the format presentation was intentionally chaotic so that it resulted in a very cluttered dynamic display. The subject's task was to use a hand controller to keep a tracking symbol, an X, on top of a target symbol, another X, which was being randomly driven (fig. 1). An X shape was used instead of the crossed needles or the "+" symbology of a flight director because the horizontal member of the "+" is not conducive to stereo presentation. (A lateral offset in the left-eye and right-eye stereo views is not possible for a horizontal line.)

In the basic tracking task, both the target symbol and the tracking symbol are presented as red X's. The presence of color coding was used to provide some declutter, thus making the task appear to be more reasonable to perform. For this condition, the target symbol was coded red, and the tracking symbol was coded blue. In the condition in which the color coding was absent, the target and the tracker were red. It was anticipated that subjects would have difficulty separating disturbance inputs from their own control inputs in this latter condition. Noise conditions, or additional clutter, were provided by the inclusion of randomly moving, differently colored X symbols. Examples of the colored symbols are zero, two extra symbols (green and purple), or four extra symbols (green, purple, white, and yellow, as shown in fig. 2). Stereo depth, which was hypothesized to declutter the display, was utilized (fig. 3) by placing any noise in a plane in front of the display monitor (25 in. away from the subject), the tracking symbol at screen depth (28 in. away from the subject), and the target symbol behind the screen (31 in. away from the subject). These particular depth values are considered to be within the guideline limits of the usable stereo viewing volume suggested in reference 20.

Preliminary trials of the tracking task, with no color coding, no noise sources, and no stereo depth cueing, suggested that the display was too confusing to yield consistently reasonable results. Figure 1 shows four intersection points that are formed by the arms of the target and tracker X symbols, of which only two are significant (one for the target and one for the tracker). The addition of boxes (a diamond shape) about the proper intersection points of the X symbols removed that ambiguity.

Eight subjects participated in this study. None of the subjects had extensive experience with stereo displays, although most had some experience in manual tracking tasks with nonstereo displays. The performance metric for the tracking task of the study was the root mean square (rms) value of the radial error during a run. The main factors of interest in the full-factorial experiment were the display viewing mode of nonstereo or stereo 3-D, the presence or absence of color coding for the declutter function, and the noise conditions for additional clutter. Training was initiated with no noise and the condition in which color coding was present (with the subject training blocked over the stereo viewing mode) to enable quick proficiency. Training then progressed through each noise condition and the condition in which color coding was absent. The rms error score was reported to the subject following each trial. Each subject achieved approximate asymptotic performance for each of the experimental conditions before data collection was begun. During data collection, three replicates of each condition were obtained from each of the eight subjects, thus resulting in 36 data runs per subject. The data collection runs were blocked across the experimental conditions and balanced across the subjects to negate any possible learning curve effects that might occur after the apparent asymptotic performance was achieved. (The order of the experimental conditions flown by each subject is presented in table 1.)

Workstation Description

The workstation was assembled with a hand controller, a display monitor, a Silicon Graphics, Incorporated, IRIS 340 VGX computer, and stereo display generation hardware. The stereo display generation software and hardware are described in detail in references 23 to 25. The hand controller input governed the vertical and the lateral positioning of the tracker symbol (i.e., the position of the intersection of the cross pieces of the X symbol). The positioning of the target symbol and of the various noise symbols was determined from disturbance function equations $H(L)$, which utilized the sum of eight sine waves of various amplitudes K_k, frequencies ω_k, and phase angle parameters ϕ_L. Table 2 presents the values of these parameters, which are based on the work documented in reference 26. The term L stands for the index of element color and axis combination. The disturbance functions repeated once every 36 sec. Each of the data runs lasted 72 sec, but data collection occurred only during the last 36 sec to remove any initial transient effects.

Experimental Results and Discussion

The investigation was designed as a full-factorial, within-subjects experiment, with subjects S, noise N, viewing mode V, color coding C, and replicates R as the factors. The objective results are presented and discussed first, and the subjective results are discussed second.

Analysis of Objective Results

The rms tracking data collected in the full-factorial experiment were analyzed using univariate analysis of variance. Table 3 is a summary of the results of this analysis.

Discussion of Objective Results

Each of the main factors of the experiment is discussed; these discussions are followed by explanations of any statistically significant second-order and third-order interaction terms.

Subjects S. The main effect of subject variability was highly significant. This result is usually expected in a precision task, and the subject variability was therefore isolated from the rest of the analyses by its inclusion as a main factor in the experiment.

Noise N. The noise conditions, or additional clutter, were provided by the inclusion of randomly moving, differently colored X symbols (either zero, two, or four extra symbols). The N factor was highly significant, and its success in adding additional clutter to the display is illustrated in figure 4. (One screen unit for the 19-in. monitor used in the experiment was equivalent to approximately 0.25 in.) Increasing the number of noise sources resulted in degradations in the mean and the standard deviations of the rms tracking error.

Viewing mode V. Stereo depth, hypothesized to declutter the display, was utilized by placing any noise in a plane in front of the display monitor, the tracking symbol at screen depth, and the target symbol behind the screen. This factor was highly significant, and better performance in the tracking task occurred in the stereo mode than in the nonstereo mode. Figure 5 illustrates the improvements obtained in both the mean and the standard deviations of the rms tracking error.

Color coding C. The presence of color coding was used to provide some declutter, thus making the task more reasonable to perform. For this condition, the target symbol was coded red, and the tracking symbol was coded blue. In the condition in which the color coding was absent, the target and the tracker were red. It was anticipated that subjects would have difficulty separating disturbance inputs from their own control inputs in this latter condition. The color coding factor was found to be statistically significant, but it was not highly significant. (The color coding factor had been anticipated to be highly significant.) Figure 6 illustrates the slight improvements obtained in both the mean and the standard deviations of the rms tracking error with the inclusion of color coding.

Replicates R. The replicate factor was not significant. This result was expected because each subject achieved approximate asymptotic performance with each condition before data collection was begun.

Subject by noise interaction $S \times N$. This interaction, which is illustrated in figure 7, was highly significant. Its significance indicates that the effect of noise varied from subject to subject. For example, subject 3 exhibited large performance changes according to the number of noise sources, but subject 6 had practically the same performance, regardless of the number of noise sources. The net effect, however, indicated that increasing the number of noise sources resulted in degradations in both the mean and the standard deviations of the rms tracking error.

Subject by viewing mode interaction $S \times V$. This interaction, which is illustrated in figure 8, was highly significant. Its significance indicates that the effect of viewing mode varied from subject to subject. For example, subject 3 exhibited large performance changes according to the viewing mode, but subject 6 had practically the same performance, regardless of the viewing mode. The net effect, however, indicated that compared with the nonstereo mode, the stereo depth did declutter the display and provide improved performance in the tracking task when stereo was present.

Subject by color coding interaction $S \times C$. This interaction, which is illustrated in figure 9, was highly significant. Its significance indicates that the effect of color coding varied from subject to subject. The Newman-Keuls testing (ref. 27) of individual means was performed at a 1-percent significance level, and only the mean performances of subjects 3 and 4 were significantly different. Hence, the decluttering benefits of color coding were effective for only two of the eight subjects.

Noise by viewing mode interaction $N \times V$. This interaction, which is illustrated in figure 10, was highly significant. Its significance indicates that the effect of noise varied with viewing mode. For the nonstereo viewing mode, increasing the number of noise sources resulted in degradations in both the means and the standard deviations of the rms tracking error. However, the number of noise sources had little effect on the performance with the stereo viewing mode. The stereo viewing mode effectively declutters the display by removing the noise sources to a depth separate from those of the tracking task elements.

Viewing mode by color coding interaction $V \times C$. This interaction, which is illustrated in figure 11, was significant. Its significance indicates that the effect of color coding varied with viewing mode. For the nonstereo viewing mode, improvements were obtained in both the mean and the standard deviations of the rms tracking error with the inclusion of color coding. However, the inclusion of color coding had little effect on the performance with the stereo viewing mode. This mode effectively declutters the display by separating in depth the target and tracking symbols, thus eliminating any of the confusion between the two symbols. (Color coding attempts to remove this same confusion.)

Subject by noise by viewing mode interaction $S \times N \times V$. This third-order interaction, which is illustrated as two $S \times N$ interactions across V in figures 12 and 13, was highly significant. Its significance indicates, after further analysis, that most of the effect of noise on subjects took place with the nonstereo viewing mode. For this mode, increasing the number of noise sources resulted in degradations in the mean rms tracking error for most of the subjects (fig. 12). However, the number of noise sources had little effect on the performance of most of the subjects with the stereo viewing mode (fig. 13). This viewing mode effectively declutters the display by removing the noise sources to a depth separate from those of the tracking task elements.

Subject by noise by color coding interaction $S \times N \times C$. This third-order interaction, which is illustrated as two $S \times N$ interactions across C in figures 14 and 15, was significant. Its significance indicates that most of the effect of noise on those subjects that were susceptible to noise took place under the condition in which color coding was absent. For this condition, increasing the number of noise sources resulted in degradations in the mean rms tracking error for most of the subjects (fig. 14). However, the number of noise sources had a smaller effect on the performance of the susceptible subjects with the condition in which color coding was present (fig. 15). Color coding was somewhat effective for some of the subjects in decluttering the display.

Subjective Results

Unstructured subject comments recorded throughout the experiment indicated that all the subjects preferred the stereo viewing mode. They felt that the stereo depth placement of the various elements effectively decluttered the display by separating the tracking task from the noise sources and allowing awareness of the relative positions of the target and tracker. In the nonstereo viewing mode, most of the subjects said that it was not to difficult to concentrate on the motion of the target and to respond with a tracker command, even without color coding to help reduce confusion with the tracker.

Concluding Remarks

The purpose of this research was to verify the potential of stereo cueing for the declutter function in a simulated tracking task. The piloting task for the study was designed to be similar to the tracking of a conventional flight director, although the format presentation was intentionally chaotic and resulted in a very cluttered dynamic display. Elements purposely introduced into the display to provide additional clutter included dynamic noise sources and the absence of color coding between the target and the tracker. It was hypothesized that the application of stereoptic cueing would effectively declutter such a format.

The results from analyzing the performances of eight subjects revealed that increasing the number of noise sources did result in degradations in performance, thus indicating the successful addition of clutter. The presence of color coding was used to provide some declutter, thus making the task appear to be more reasonable to perform. It was anticipated that subjects would have less difficulty separating disturbance inputs from their own control inputs in this condition. The presence of color coding provided some improvement in tracking performance, but the apparent decluttering benefits of color coding were attributable to only two of the eight subjects.

The objective and subjective results for the stereo presentations have consistently demonstrated it to be an effective decluttering tool. Stereo cueing also effectively offset the cluttering effects of both the noise condition and the color coding condition. The number of noise sources had little effect on the performance with the stereo viewing mode. This stereo mode effectively decluttered the display by moving the noise sources to a depth separate from those of the tracking task elements. Likewise, the inclusion and exclusion of color coding had little effect on the performance with the stereo viewing mode. This stereo mode effectively decluttered the display by separating in depth the target and tracking symbols, thus eliminating any of the confusion between the two symbols.

The potential of stereo cueing to declutter complex informational displays has therefore been verified; this ability to declutter is an additional benefit from the application of stereoptic cueing.

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Table 1. Experimental Condition

Subject	Run	Viewing mode	Color coding	Noise sources	Replicate
1	1	Nonstereo	Present	0	1
1	2	Nonstereo	Present	2	1
1	3	Nonstereo	Present	4	1
1	4	Nonstereo	Present	0	2
1	5	Nonstereo	Present	4	2
1	6	Nonstereo	Present	2	2
1	7	Nonstereo	Present	4	3
1	8	Nonstereo	Present	2	3
1	9	Nonstereo	Present	0	3
1	10	Nonstereo	Absent	4	1
1	11	Nonstereo	Absent	2	1
1	12	Nonstereo	Absent	0	1
1	13	Nonstereo	Absent	2	2
1	14	Nonstereo	Absent	0	2
1	15	Nonstereo	Absent	4	2
1	16	Nonstereo	Absent	0	3
1	17	Nonstereo	Absent	4	3
1	18	Nonstereo	Absent	2	3
1	19	Stereo	Present	0	1
1	20	Stereo	Present	4	1
1	21	Stereo	Present	2	1
1	22	Stereo	Present	2	2
1	23	Stereo	Present	0	2
1	24	Stereo	Present	4	2
1	25	Stereo	Present	4	3
1	26	Stereo	Present	0	3
1	27	Stereo	Present	2	3
1	28	Stereo	Absent	4	1
1	29	Stereo	Absent	2	1
1	30	Stereo	Absent	0	1
1	31	Stereo	Absent	4	2
1	32	Stereo	Absent	0	2
1	33	Stereo	Absent	2	2
1	34	Stereo	Absent	2	3
1	35	Stereo	Absent	0	3
1	36	Stereo	Absent	4	3
2	1	Stereo	Present	0	1
2	2	Stereo	Present	2	1
2	3	Stereo	Present	4	1
2	4	Stereo	Present	0	2
2	5	Stereo	Present	4	2
2	6	Stereo	Present	2	2
2	7	Stereo	Present	4	3
2	8	Stereo	Present	2	3
2	9	Stereo	Present	0	3
2	10	Stereo	Absent	4	1
2	11	Stereo	Absent	2	1
2	12	Stereo	Absent	0	1

Table 1. Continued

Subject	Run	Viewing mode	Color coding	Noise sources	Replicate
2	13	Stereo	Absent	2	2
2	14	Stereo	Absent	0	2
2	15	Stereo	Absent	4	2
2	16	Stereo	Absent	0	3
2	17	Stereo	Absent	4	3
2	18	Stereo	Absent	2	3
2	19	Nonstereo	Present	0	1
2	20	Nonstereo	Present	4	1
2	21	Nonstereo	Present	2	1
2	22	Nonstereo	Present	2	2
2	23	Nonstereo	Present	0	2
2	24	Nonstereo	Present	4	2
2	25	Nonstereo	Present	4	3
2	26	Nonstereo	Present	0	3
2	27	Nonstereo	Present	2	3
2	28	Nonstereo	Absent	4	1
2	29	Nonstereo	Absent	2	1
2	30	Nonstereo	Absent	0	1
2	31	Nonstereo	Absent	4	2
2	32	Nonstereo	Absent	0	2
2	33	Nonstereo	Absent	2	2
2	34	Nonstereo	Absent	2	3
2	35	Nonstereo	Absent	0	3
2	36	Nonstereo	Absent	4	3
3	1	Nonstereo	Absent	0	1
3	2	Nonstereo	Absent	2	1
3	3	Nonstereo	Absent	4	1
3	4	Nonstereo	Absent	0	2
3	5	Nonstereo	Absent	4	2
3	6	Nonstereo	Absent	2	2
3	7	Nonstereo	Absent	4	3
3	8	Nonstereo	Absent	2	3
3	9	Nonstereo	Absent	0	3
3	10	Nonstereo	Present	4	1
3	11	Nonstereo	Present	2	1
3	12	Nonstereo	Present	0	1
3	13	Nonstereo	Present	2	2
3	14	Nonstereo	Present	0	2
3	15	Nonstereo	Present	4	2
3	16	Nonstereo	Present	0	3
3	17	Nonstereo	Present	4	3
3	18	Nonstereo	Present	2	3
3	19	Stereo	Absent	0	1
3	20	Stereo	Absent	4	1
3	21	Stereo	Absent	2	1
3	22	Stereo	Absent	2	2
3	23	Stereo	Absent	0	2
3	24	Stereo	Absent	4	2

Table 1. Continued

Subject	Run	Viewing mode	Color coding	Noise sources	Replicate
3	25	Stereo	Absent	4	3
3	26	Stereo	Absent	0	3
3	27	Stereo	Absent	2	3
3	28	Stereo	Present	4	1
3	29	Stereo	Present	2	1
3	30	Stereo	Present	0	1
3	31	Stereo	Present	4	2
3	32	Stereo	Present	0	2
3	33	Stereo	Present	2	2
3	34	Stereo	Present	2	3
3	35	Stereo	Present	0	3
3	36	Stereo	Present	4	3
4	1	Stereo	Absent	0	1
4	2	Stereo	Absent	2	1
4	3	Stereo	Absent	4	1
4	4	Stereo	Absent	0	2
4	5	Stereo	Absent	4	2
4	6	Stereo	Absent	2	2
4	7	Stereo	Absent	4	3
4	8	Stereo	Absent	2	3
4	9	Stereo	Absent	0	3
4	10	Stereo	Present	4	1
4	11	Stereo	Present	2	1
4	12	Stereo	Present	0	1
4	13	Stereo	Present	2	2
4	14	Stereo	Present	0	2
4	15	Stereo	Present	4	2
4	16	Stereo	Present	0	3
4	17	Stereo	Present	4	3
4	18	Stereo	Present	2	3
4	19	Nonstereo	Absent	0	1
4	20	Nonstereo	Absent	4	1
4	21	Nonstereo	Absent	2	1
4	22	Nonstereo	Absent	2	2
4	23	Nonstereo	Absent	0	2
4	24	Nonstereo	Absent	4	2
4	25	Nonstereo	Absent	4	3
4	26	Nonstereo	Absent	0	3
4	27	Nonstereo	Absent	2	3
4	28	Nonstereo	Present	4	1
4	29	Nonstereo	Present	2	1
4	30	Nonstereo	Present	0	1
4	31	Nonstereo	Present	4	2
4	32	Nonstereo	Present	0	2
4	33	Nonstereo	Present	2	2
4	34	Nonstereo	Present	2	3
4	35	Nonstereo	Present	0	3
4	36	Nonstereo	Present	4	3

Table 1. Continued

Subject	Run	Viewing mode	Color coding	Noise sources	Replicate
5	1	Nonstereo	Present	0	1
5	2	Nonstereo	Present	2	1
5	3	Nonstereo	Present	4	1
5	4	Nonstereo	Present	0	2
5	5	Nonstereo	Present	4	2
5	6	Nonstereo	Present	2	2
5	7	Nonstereo	Present	4	3
5	8	Nonstereo	Present	2	3
5	9	Nonstereo	Present	0	3
5	10	Nonstereo	Absent	4	1
5	11	Nonstereo	Absent	2	1
5	12	Nonstereo	Absent	0	1
5	13	Nonstereo	Absent	2	2
5	14	Nonstereo	Absent	0	2
5	15	Nonstereo	Absent	4	2
5	16	Nonstereo	Absent	0	3
5	17	Nonstereo	Absent	4	3
5	18	Nonstereo	Absent	2	3
5	19	Stereo	Absent	0	1
5	20	Stereo	Absent	4	1
5	21	Stereo	Absent	2	1
5	22	Stereo	Absent	2	2
5	23	Stereo	Absent	0	2
5	24	Stereo	Absent	4	2
5	25	Stereo	Absent	4	3
5	26	Stereo	Absent	0	3
5	27	Stereo	Absent	2	3
5	28	Stereo	Present	4	1
5	29	Stereo	Present	2	1
5	30	Stereo	Present	0	1
5	31	Stereo	Present	4	2
5	32	Stereo	Present	0	2
5	33	Stereo	Present	2	2
5	34	Stereo	Present	2	3
5	35	Stereo	Present	0	3
5	36	Stereo	Present	4	3
6	1	Stereo	Present	0	1
6	2	Stereo	Present	2	1
6	3	Stereo	Present	4	1
6	4	Stereo	Present	0	2
6	5	Stereo	Present	4	2
6	6	Stereo	Present	2	2
6	7	Stereo	Present	4	3
6	8	Stereo	Present	2	3
6	9	Stereo	Present	0	3
6	10	Stereo	Absent	4	1
6	11	Stereo	Absent	2	1
6	12	Stereo	Absent	0	1

Table 1. Continued

Subject	Run	Viewing mode	Color coding	Noise sources	Replicate
6	13	Stereo	Absent	2	2
6	14	Stereo	Absent	0	2
6	15	Stereo	Absent	4	2
6	16	Stereo	Absent	0	3
6	17	Stereo	Absent	4	3
6	18	Stereo	Absent	2	3
6	19	Nonstereo	Absent	0	1
6	20	Nonstereo	Absent	4	1
6	21	Nonstereo	Absent	2	1
6	22	Nonstereo	Absent	2	2
6	23	Nonstereo	Absent	0	2
6	24	Nonstereo	Absent	4	2
6	25	Nonstereo	Absent	4	3
6	26	Nonstereo	Absent	0	3
6	27	Nonstereo	Absent	2	3
6	28	Nonstereo	Present	4	1
6	29	Nonstereo	Present	2	1
6	30	Nonstereo	Present	0	1
6	31	Nonstereo	Present	4	2
6	32	Nonstereo	Present	0	2
6	33	Nonstereo	Present	2	2
6	34	Nonstereo	Present	2	3
6	35	Nonstereo	Present	0	3
6	36	Nonstereo	Present	4	3
7	1	Nonstereo	Present	0	1
7	2	Nonstereo	Present	2	1
7	3	Nonstereo	Present	4	1
7	4	Nonstereo	Present	0	2
7	5	Nonstereo	Present	4	2
7	6	Nonstereo	Present	2	2
7	7	Nonstereo	Present	4	3
7	8	Nonstereo	Present	2	3
7	9	Nonstereo	Present	0	3
7	10	Nonstereo	Absent	4	1
7	11	Nonstereo	Absent	2	1
7	12	Nonstereo	Absent	0	1
7	13	Nonstereo	Absent	2	2
7	14	Nonstereo	Absent	0	2
7	15	Nonstereo	Absent	4	2
7	16	Nonstereo	Absent	0	3
7	17	Nonstereo	Absent	4	3
7	18	Nonstereo	Absent	2	3
7	19	Stereo	Absent	0	1
7	20	Stereo	Absent	4	1
7	21	Stereo	Absent	2	1
7	22	Stereo	Absent	2	2
7	23	Stereo	Absent	0	2
7	24	Stereo	Absent	4	2

Table 1. Concluded

Subject	Run	Viewing mode	Color coding	Noise sources	Replicate
7	25	Stereo	Absent	4	3
7	26	Stereo	Absent	0	3
7	27	Stereo	Absent	2	3
7	28	Stereo	Present	4	1
7	29	Stereo	Present	2	1
7	30	Stereo	Present	0	1
7	31	Stereo	Present	4	2
7	32	Stereo	Present	0	2
7	33	Stereo	Present	2	2
7	34	Stereo	Present	2	3
7	35	Stereo	Present	0	3
7	36	Stereo	Present	4	3
8	1	Stereo	Present	0	1
8	2	Stereo	Present	2	1
8	3	Stereo	Present	4	1
8	4	Stereo	Present	0	2
8	5	Stereo	Present	4	2
8	6	Stereo	Present	2	2
8	7	Stereo	Present	4	3
8	8	Stereo	Present	2	3
8	9	Stereo	Present	0	3
8	10	Stereo	Absent	4	1
8	11	Stereo	Absent	2	1
8	12	Stereo	Absent	0	1
8	13	Stereo	Absent	2	2
8	14	Stereo	Absent	0	2
8	15	Stereo	Absent	4	2
8	16	Stereo	Absent	0	3
8	17	Stereo	Absent	4	3
8	18	Stereo	Absent	2	3
8	19	Nonstereo	Absent	0	1
8	20	Nonstereo	Absent	4	1
8	21	Nonstereo	Absent	2	1
8	22	Nonstereo	Absent	2	2
8	23	Nonstereo	Absent	0	2
8	24	Nonstereo	Absent	4	2
8	25	Nonstereo	Absent	4	3
8	26	Nonstereo	Absent	0	3
8	27	Nonstereo	Absent	2	3
8	28	Nonstereo	Present	4	1
8	29	Nonstereo	Present	2	1
8	30	Nonstereo	Present	0	1
8	31	Nonstereo	Present	4	2
8	32	Nonstereo	Present	0	2
8	33	Nonstereo	Present	2	2
8	34	Nonstereo	Present	2	3
8	35	Nonstereo	Present	0	3
8	36	Nonstereo	Present	4	3

Table 2. Parameters for Disturbance Functions

$$\left[\begin{array}{c} H(L) = G_L \sum_{k=1}^{8} K_k \sin(\omega_k n \; \Delta t + \phi_L), \text{ where } G_L \text{ is screen gain,} \\ n \text{ is discrete time interval number, and } \Delta t \text{ is } 1/60 \text{ sec} \end{array}\right]$$

(a) Parameters of eight sine waves

k	ω_k, rad/sec	K_k
1	0.35	1.0
2	0.70	−1.0
3	1.05	0.9
4	1.75	0.9
5	2.62	0.8
6	3.49	−0.6
7	6.28	−0.4
8	10.50	0.1

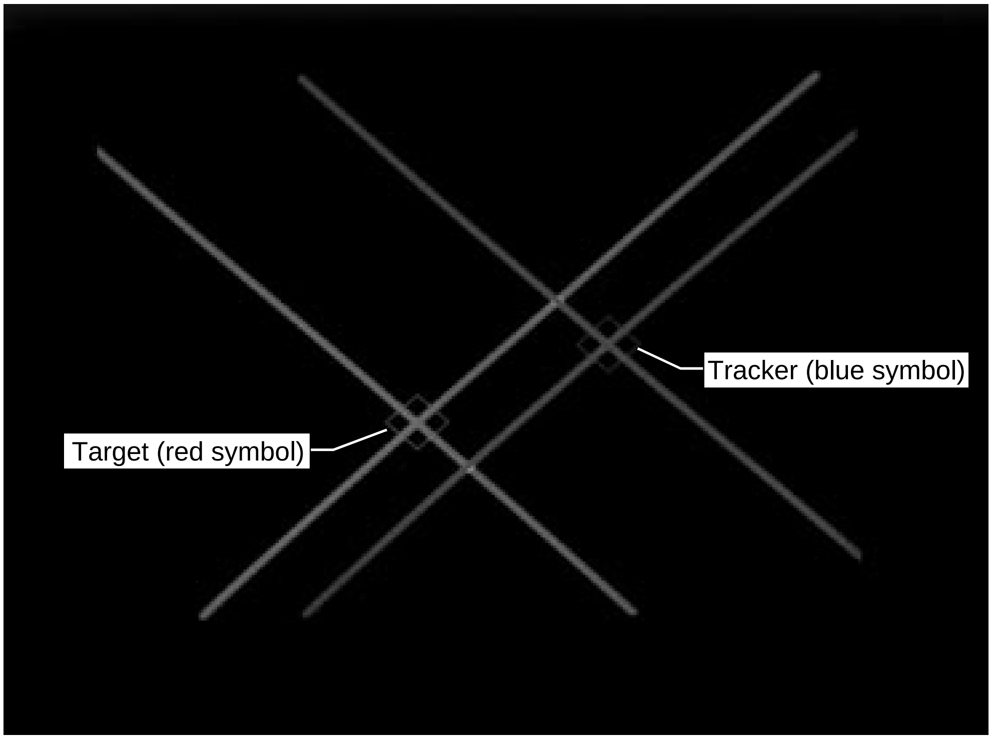
(b) Parameter of display elements

Element	Color	Axis	L	G_L, screen units	ϕ_L, rad
Target	Red	Vertical	1	1.4	0
		Lateral	2	−1.4	5.23
Noise 1	Green	Vertical	3	1.4	2.09
		Lateral	4	1.4	3.14
Noise 2	Purple	Vertical	5	1.4	4.19
		Lateral	6	1.4	2.00
Noise 3	White	Vertical	7	1.4	3.50
		Lateral	8	1.4	1.50
Noise 4	Yellow	Vertical	9	1.4	1.01
		Lateral	10	1.4	2.75

Table 3. Summary of Analysis of Variance

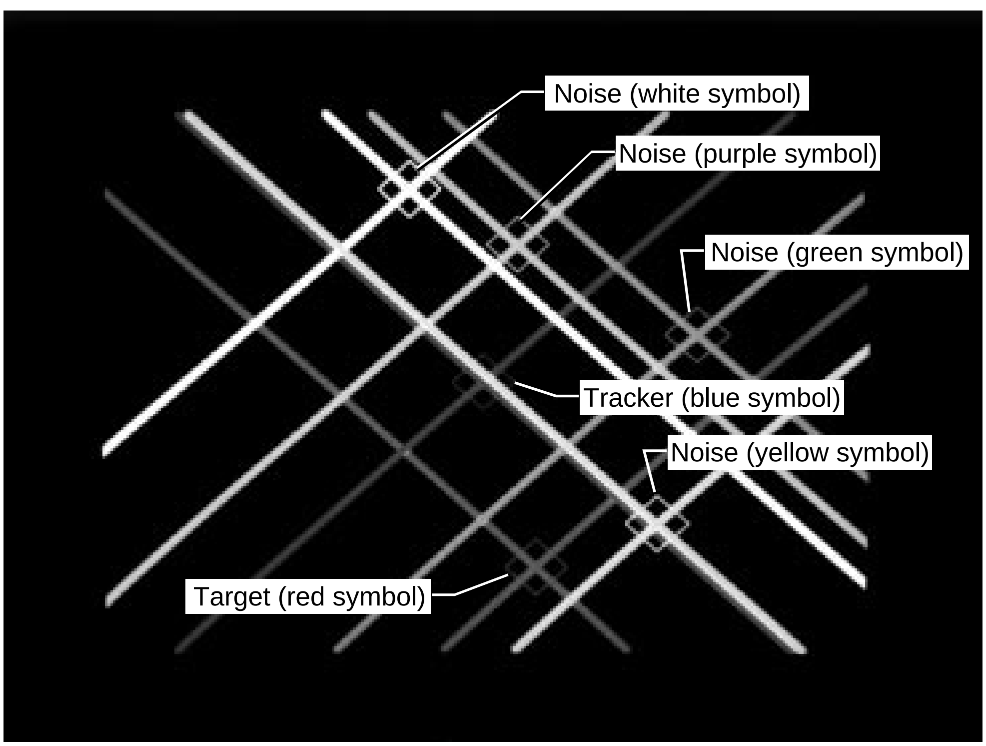
Factors	Degrees of freedom	Significance[a] level
Subjects, S	7	**
Noise, N	2	**
Viewing mode, V	1	**
Color, C	1	*
Replicates, R	2	-
$S \times N$	14	**
$S \times V$	7	**
$S \times C$	7	**
$N \times V$	2	**
$N \times C$	2	-
$V \times C$	1	*
$S \times N \times V$	14	**
$S \times N \times C$	14	*
$N \times V \times C$	2	-
Error	211	

[a]Significance:
-Not significant at levels considered.
*Significant at 5-percent level.
**Significant at 1-percent level.



L-92-11517

Figure 1. Basic tracking task display.



L-92-11520

Figure 2. Addition of four noise sources to basic tracking task display.

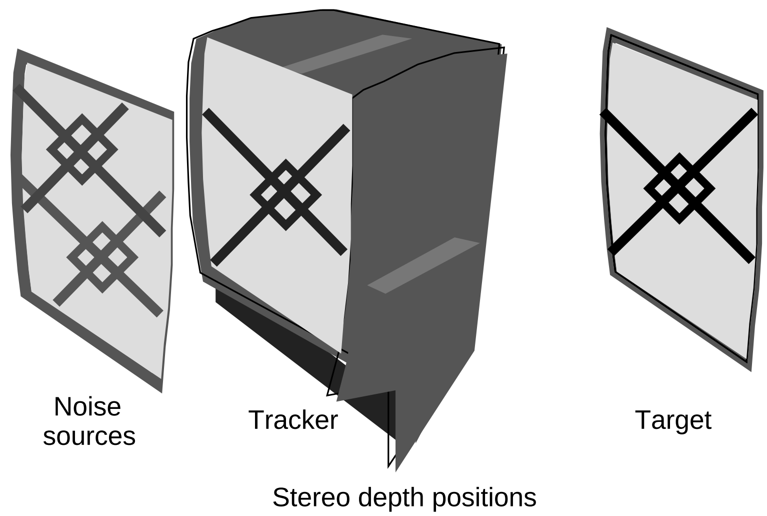


Figure 3. Use of stereo depth to declutter tracking task display.

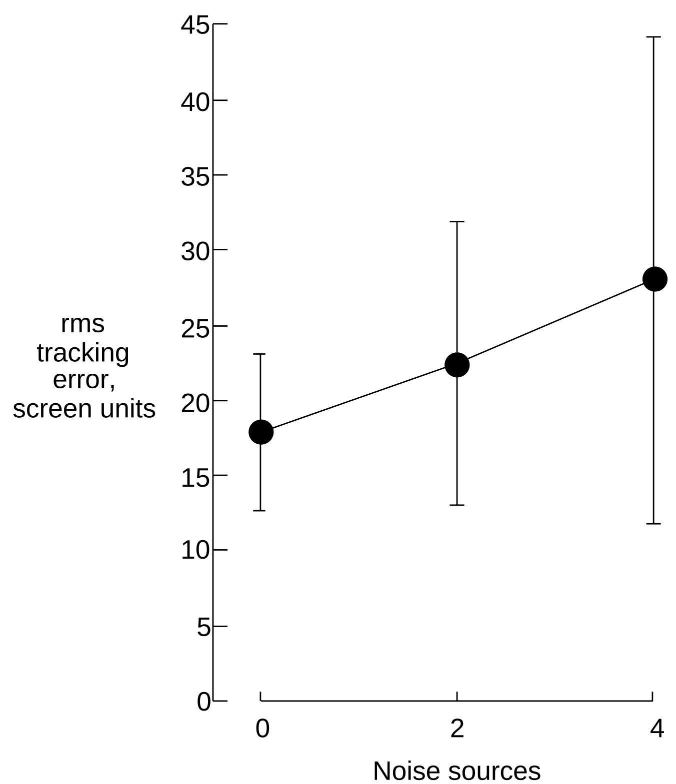


Figure 4. Effect of adding noise sources on performance of tracking task.

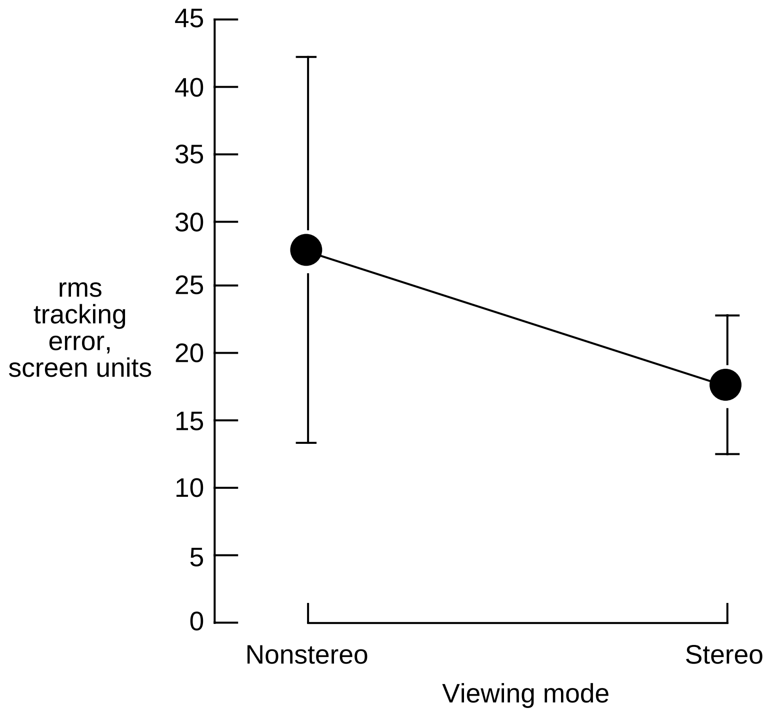


Figure 5. Effect of viewing mode on performance of tracking task.

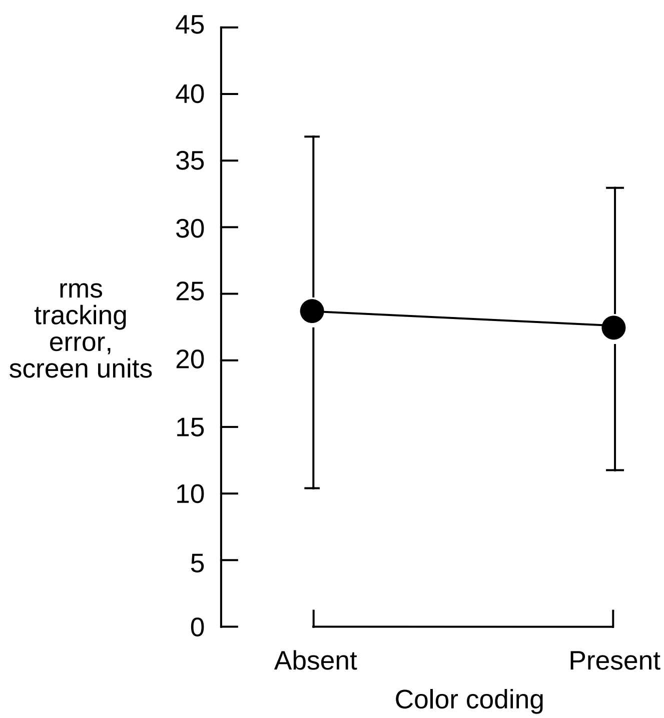


Figure 6. Effect of color coding on performance of tracking task.

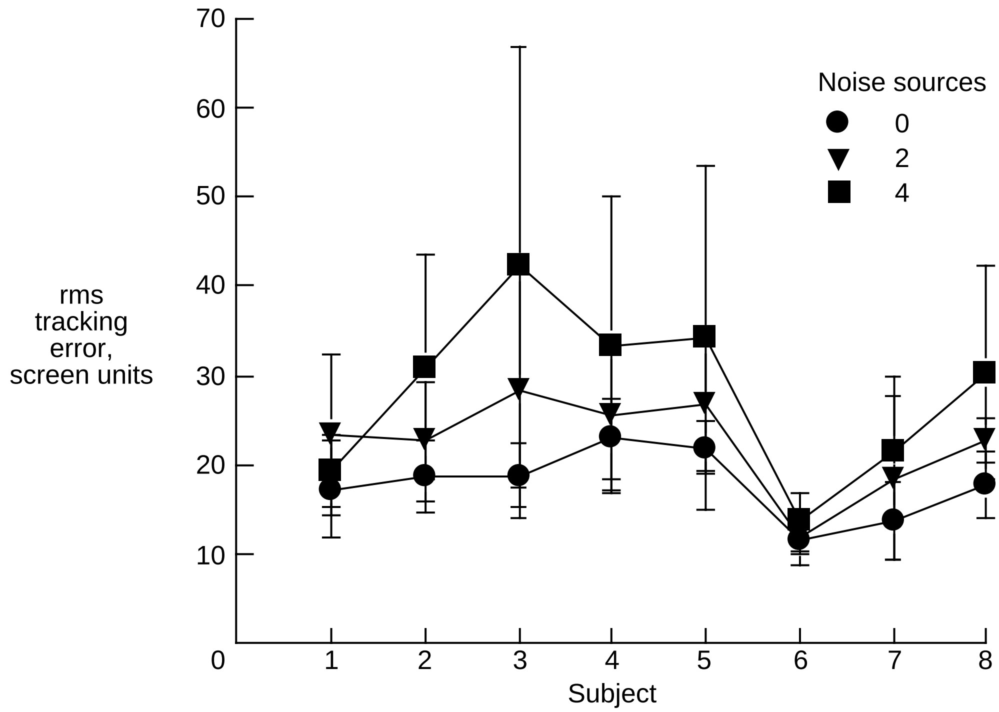


Figure 7. Effect of adding noise sources on performance of tracking task for each subject.

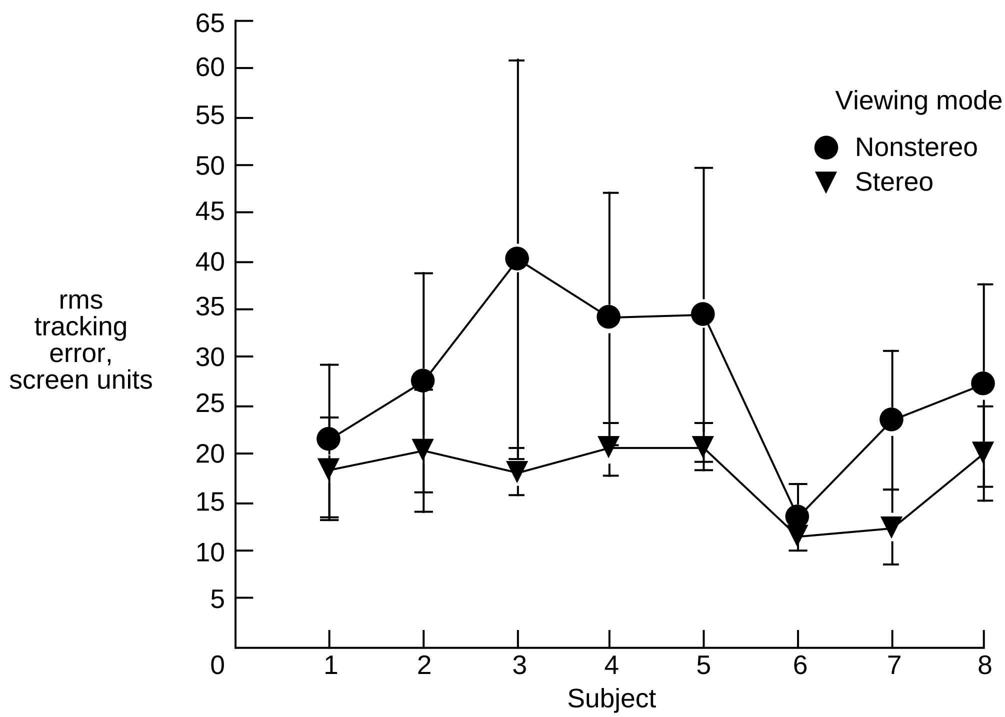


Figure 8. Effect of viewing mode on performance of tracking task for each subject.

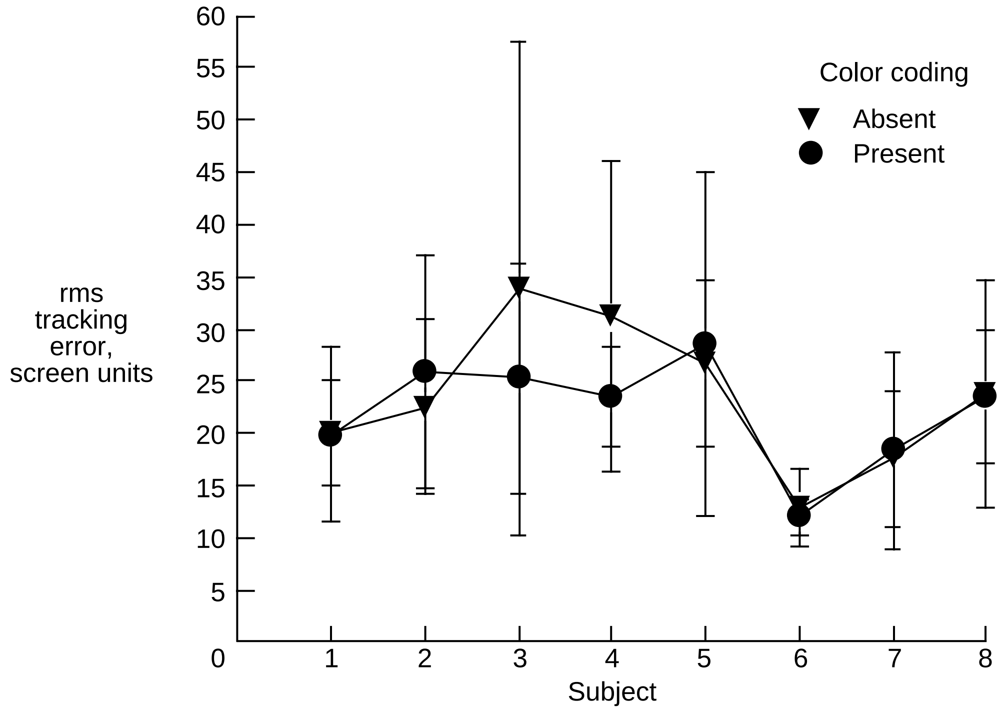


Figure 9. Effect of color coding on performance of tracking task for each subject.

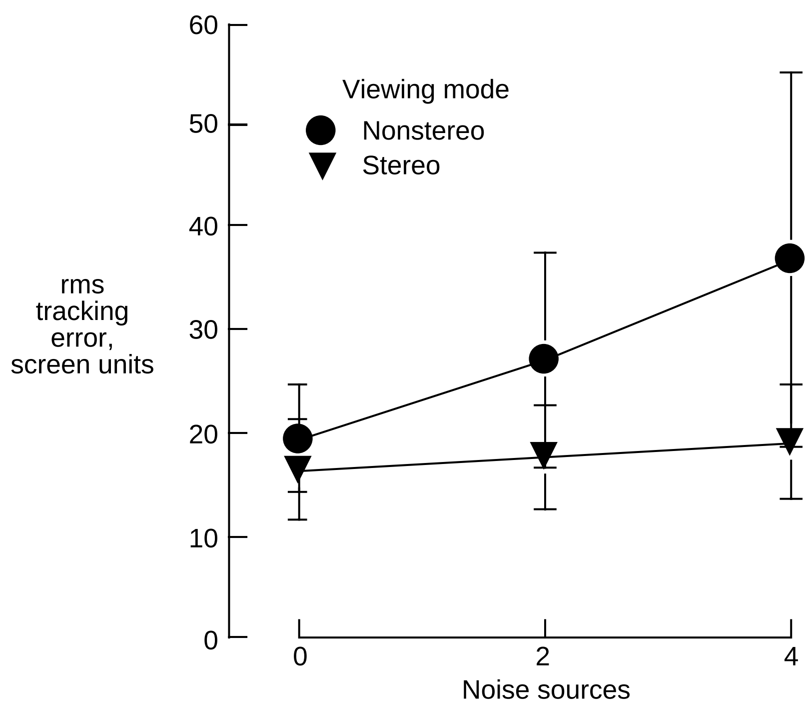


Figure 10. Effect of adding noise sources on performance of tracking task for each viewing mode.

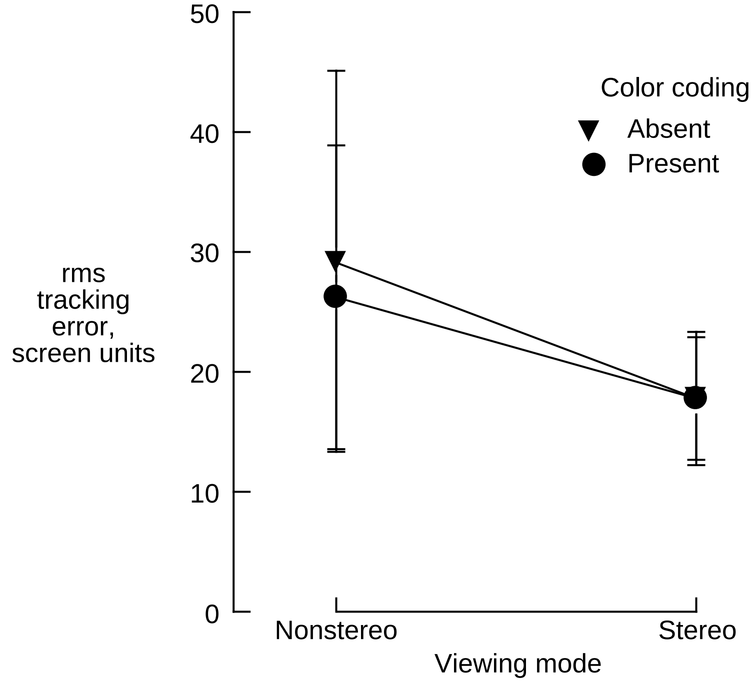


Figure 11. Effect of color coding on performance of tracking task for each viewing mode.

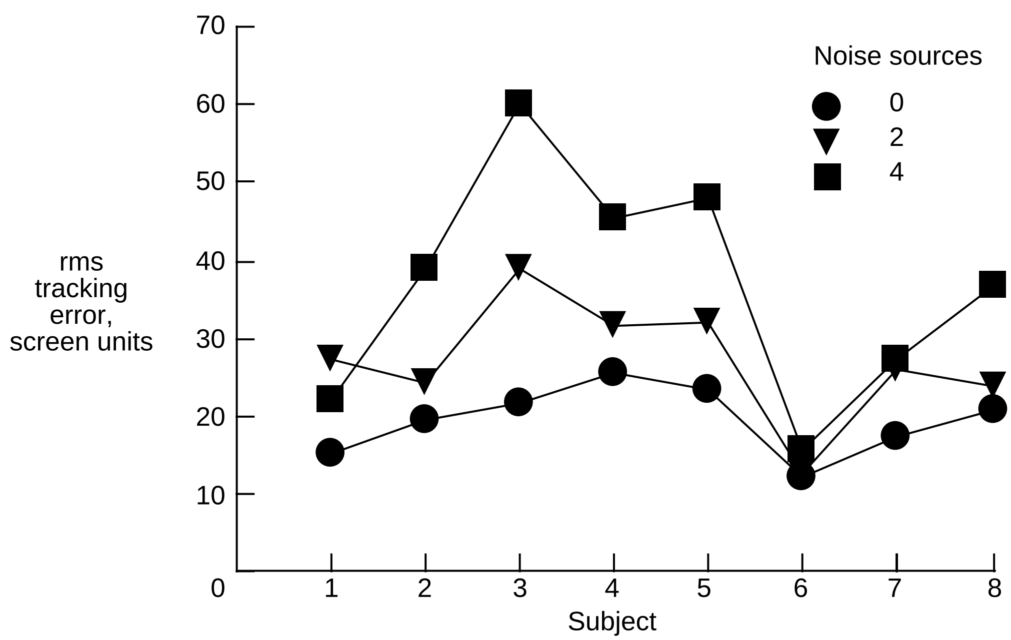


Figure 12. Effect of adding noise sources on tracking task performance of each subject for nonstereo viewing mode.

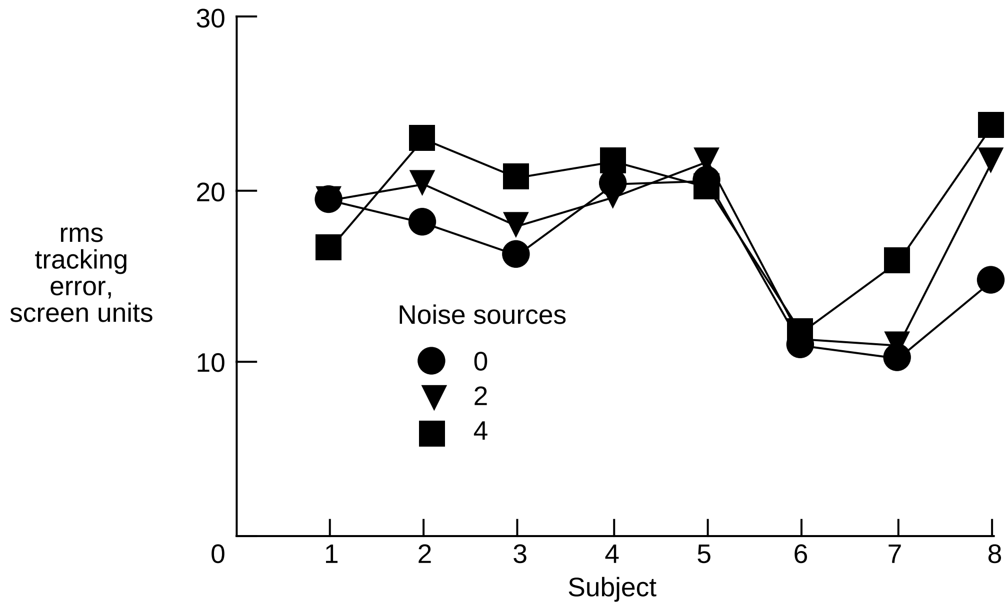


Figure 13. Effect of adding noise sources on tracking task performance of each subject for stereo viewing mode.

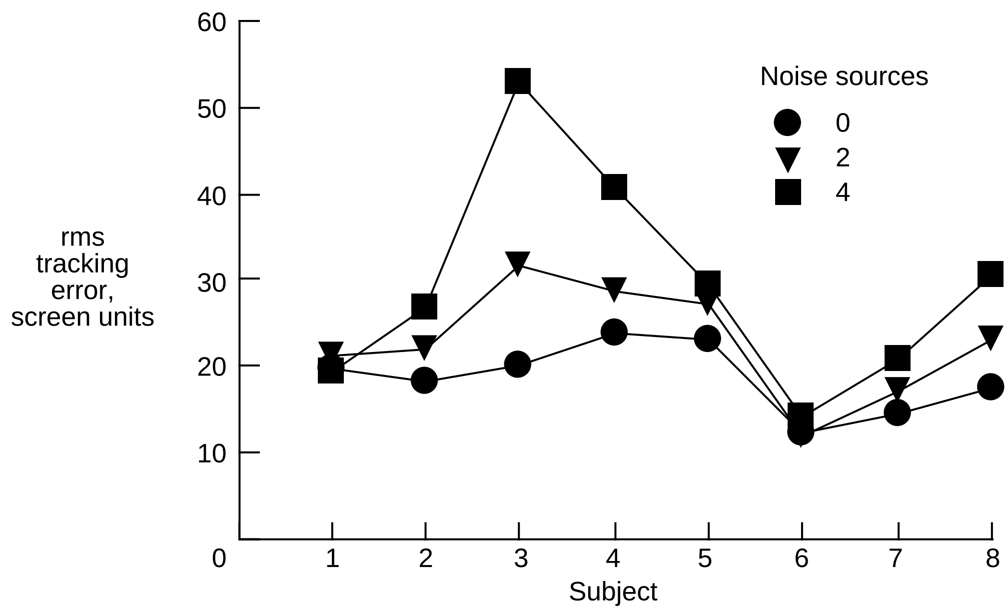


Figure 14. Effect of adding noise sources on tracking task performance of each subject for condition in which color coding was absent.

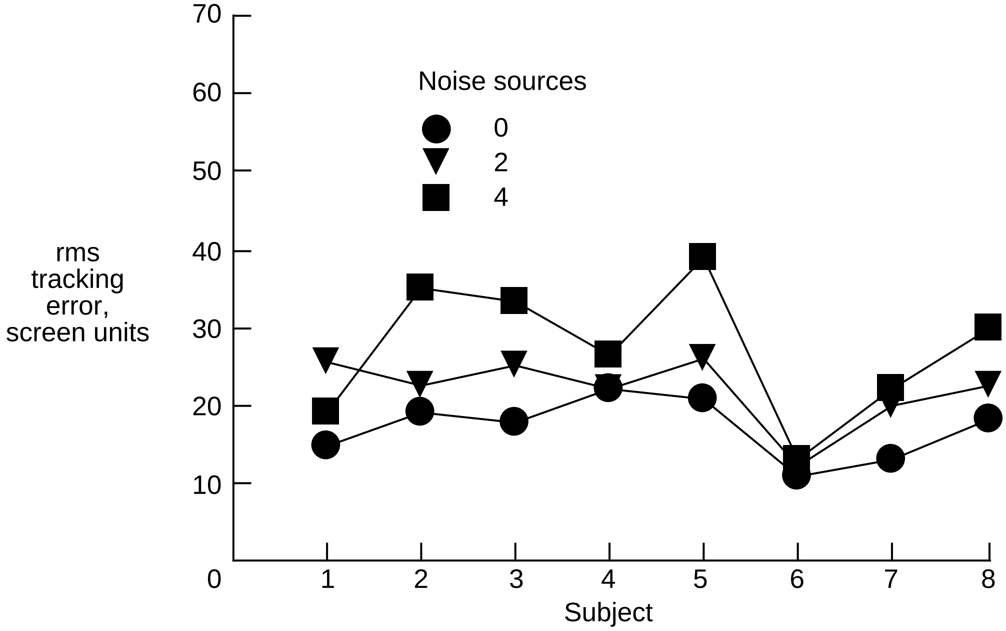


Figure 15. Effect of adding noise sources on tracking task performance of each subject for condition in which color coding was present.

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13. ABSTRACT *(Maximum 200 words)*
The application of stereo technology to new, integrated pictorial display formats has been effective in situational awareness enhancements, and stereo has been postulated to be effective for the declutter of complex informational displays. This paper reports a full-factorial workstation experiment performed to verify the potential benefits of stereo cueing for the declutter function in a simulated tracking task. The experimental symbology was designed similar to that of a conventional flight director, although the format was an intentionally confused presentation that resulted in a very cluttered dynamic display. The subject's task was to use a hand controller to keep a tracking symbol, an "X," on top of a target symbol, another X, which was being randomly driven. In the basic tracking task, both the target symbol and the tracking symbol were presented as red X's. The presence of color coding was used to provide some declutter, thus making the task more reasonable to perform. For this condition, the target symbol was coded red, and the tracking symbol was coded blue. Noise conditions, or additional clutter, were provided by the inclusion of randomly moving, differently colored X symbols. Stereo depth, which was hypothesized to declutter the display, was utilized by placing any noise in a plane in front of the display monitor, the tracking symbol at screen depth, and the target symbol behind the screen. The results from analyzing the performances of eight subjects revealed that the stereo presentation effectively offsets the cluttering effects of both the noise and the absence of color coding. The potential of stereo cueing to declutter complex informational displays has therefore been verified; this ability to declutter is an additional benefit from the application of stereoptic cueing to pictorial flight displays.

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